States
nent of
ure
eration
uthern DA's
d CES'

Economic
Research
Service

ERS Staff Report
No. AGESS 810721

Overall Evaluation

Beltwide Boll Weevil/Cotton Insect Management Programs

OVERALL EVALUATION

OF

BELTWIDE BOLL WEEVIL/COTTON INSECT MANAGEMENT PROGRAMS

by

The Overall Evaluation Team

of the

USDA Interagency Working Group on Boll Weevil Programs

In cooperation with Southern

State Departments of Agriculture,

Agricultural Experiment Stations,

and

Cooperative Extension Services

FINAL REPORT

May 15, 1981

OVERALL EVALUATION: Beltwide Boll Weevil/Cotton Insect Management Programs. Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C. 20250. July 1981. Staff Report No. AGESS810721.

ABSTRACT

Two boll weevil/cotton insect management trials, conducted during 1978-80, demonstrated the technical and operational feasibility of eradicating a boll weevil population from a geographic area or eliminating the need for boll weevil treatments during the cotton-growing season. Six cotton insect management programs were specified and evaluated for application in the boll weevil infested areas of the Cotton Belt. The Optimum Pest Management with No Incentive and Boll Weevil Eradication (OPM-NI-BWE) Program would yield substantially higher total economic and environmental benefits than the other programs. The OPM with No Incentive Program was estimated to yield the highest benefit/cost ratio in terms of public expenditures.

Keywords: Cotton, boll weevil, insect management, insecticides, biological impacts, economic impacts, environmental impacts

PREFACE

This report summarizes and analyzes the economic, biological, and environmental impacts of six cotton insect management programs for the boll weevil-infested areas of the Cotton Belt. It also presents highlights of two large-area boll weevil/cotton insect management trials. The information in this report was compiled mainly from appendices, A through H, developed by separate teams and groups associated with the conduct of the trials and the evaluations. Each appendix is a separate numbered report; all are included in the References at the back of this report.

Representatives of several cooperating agencies and cotton industry groups contributed to the conduct of the trials and the evaluations. Some but not all are recognized in this report and the appendices.

The Economics and Statistics Service (ESS), USDA, was responsible for the overall evaluation, aided by an interdisciplinary Federal and State interagency team:

Velmar Davis, ESS, USDA
Leader, Overall Evaluation Team

William Cross, SEA-AR, USDA
Leader, Biological Evaluation Team

Irving Starbird, ESS, USDA
Leader, Economic Evaluation Team

Robert Williamson, APHIS, USDA
Leader, Environmental Evaluation Team

James Brazzel, APHIS, USDA
Program Director, Boll Weevil
Eradication Trial

David Young
Leader, Extension Entomology
Mississippi Cooperative Ext. Service
Program Director, Optimum Pest
Management Trial

Ted Moriak, OBP&E, USDA
Leader, Program Definition
and Cost Facilitator Group

Katherine Reichelderfer, ESS, USDA
Leader, Delphi--Insecticide Use
and Lint Yields

Edwin Johnson
Deputy Assistant Director for
Pesticide Programs, EPA

Ronald Lacewell
Dept. of Agricultural Economics
Texas A&M University, representing
the Southern States Agricultural
Experiment Stations

Louie H. Senn
Plant Pest Regulatory Service,
South Carolina, representing the
Southern States Depts. of Agric.

Ronald Smith
Pest Management Specialist
Auburn University, representing
the Southern States Cooperative
Extension Services

CONTENTS

TABLES, FIGURES AND APPENDICES

Page

TABLES

FIGURES

FIGURES (CONTINUED)

APPENDICES

ACRONYMS

APHIS	Animal and Plant Health Inspection Service, USDA
ASCS	Agricultural Stabilization and Conservation Service
B/C	Benefit/Cost Ratio
BWE	Boll Weevil Eradication or Trial
CES	Cooperative Extension Service
CIC	Current Insect Control
CIC-BWE	Current Insect Control with Boll Weevil Eradication
ESS	Economics and Statistics Service, USDA
MOPM	Modified Optimum Pest Management Option
NCDA	North Carolina Department of Agriculture
OBP&E	Office of Budget, Planning and Evaluation, USDA
OPM	Optimum Pest Management Option or Trial
OPM-NI-BWE	Optimum Pest Management with No Incentive and Boll Weevil Eradication
OPM-I	Optimum Pest Management with Continuing Full Incentive Payments to Producers for Diapause and/or Pinhead Square Treatments
OPM-NI	Optimum Pest Management with No Incentive Payments to Producers
OPM-PI	Optimum Pest Management with Phased Incentive Payment to Producers
OPMREEAC	Optimum Pest Management Regional Extension Education Advisory Committee
SEA-AR	Science and Education Administration-Agricultural Research, USDA
VADAC	Virginia Department of Agriculture and Commerce

SUMMARY

- The boll weevil, a major insect pest of cotton, is directly responsible for yield losses on about 7 million acres. It is indirectly responsible for additional losses because weevil treatments destroy the natural predators of bollworms and tobacco budworms.

- Producers spend nearly $200 million annually to reduce the damage from boll weevil and other cotton insects in the weevil-infested areas of the Cotton Belt.

- Research conducted during the 1960's and 1970's led to two large-area cotton insect management trials, completed in 1980. These trials demonstrated the technical and operational feasibility of eradicating an established boll weevil population or of avoiding the need for in-season treatments to control the boll weevil.

- Based on the success of the trials and previous research and experience in managing cotton insects in other areas, six cotton insect management programs for the boll weevil infested areas of the Cotton Belt were specified and evaluated for their biological, economic, and environmental impacts.

- Compared with Current Insect Control (CIC), the five new programs are estimated to be able to increase cotton lint yields between 3 and 5 percent: Optimum Pest Management with Phased Incentives (OPM-PI) and OPM with No Incentives (OPM-NI), 3 percent; OPM with Incentives (OPM-I) and CIC with Boll Weevil Eradication (CIC-BWE), 4 percent; and OPM-NI-BWE, 5 percent.

- The programs would also reduce producers' insect control costs: OPM-I, 23 percent; OPM-PI and OPM-NI, 11 percent; CIC-BWE, 25 percent and OPM-NI-BWE, 28 percent.

- The programs would also lead to higher net returns to cotton producers in areas heavily infested with weevils. Net returns would be lower for producers in weevil-free regions because the additional production would tend to reduce cotton prices. Price declines may more than offset the increases in production and decreases in costs such that the total returns to the industry could fall.

- Consumers would gain from higher production and lower prices of cotton goods. There may also be larger production and marginally lower prices of some other crops. The gains would greatly exceed the reduced value of industry output and the expenditures of public funds to implement the programs.

- In response to lower prices, cotton exports would increase by 2 to 3 percent and the U.S. balance of payments would be impacted favorably by all of the proposed programs.

- Estimated present value of market benefits and public expenditure benefit/cost ratios for the proposed programs compared with CIC were:

	OPM-I	OPM-PI	OPM-NI	CIC-BWE	OPM-NI-BWE
Net market benefits ($ billion)	3.1	2.5	2.6	2.7	3.9
B/C ratio	8:1	21:1	44:1	18:1	17:1

  These estimates were based on a discount rate of 7-1/8 percent and producers sharing 50 percent of the operational costs of the two eradication programs.

- Sensitivity analyses, based on different assumptions, changed the estimates of market benefits and B/C ratios but did not change the relative ranking of the programs.

- The substantial quantities of insecticides used in cotton production pose environmental concerns. Technical analyses of risks and hazards in the trial areas and selected river basins throughout the Cotton Belt indicated that no substantial adverse environmental effects would be expected from CIC, OPM-I, or OPM-NI-BWE programs. The other three programs were not evaluated.

- Insecticide use indices (proxy for environmental quality), based on total pounds of active ingredients of insecticides, were the most favorable for the boll weevil eradication programs: CIC=100; OPM-I=77; OPM-PI=72; OPM-NI=72; CIC-BWE=62; and OPM-NI-BWE=54.

- A ranking of the programs based on key biological, economic, and environmental variables indicated that CIC, OPM-NI and OPM-NI-BWE programs were the most viable for beltwide implementation.

- A comparison of programs based on the extent of insecticide use suggests that the eradication programs should have the least risk of causing insecticide resistance to bollworms and tobacco budworms.

- All proposed programs would result in reduced energy use in terms of reduced insecticides, fewer applications, and more pounds of cotton per acre. The two eradication programs would result in the largest improvement in energy efficiency.

INTRODUCTION

Cotton is a major crop grown throughout the southern United States, where annual production is between 10 million and 14 million bales. Farm value of the 1979-80 crop was $5.1 billion. Profitable cotton production and effective insect control have been closely related since the boll weevil, *Anthonomous grandis* Boheman, entered the United States from Mexico in 1892 (1). 1/ Since that time, much research has been directed toward the control of the boll weevil and other cotton insects.

Despite extensive use of many insect control practices by producers, insects have caused losses to cotton estimated at 7 to 19 percent of the crop in recent years. Additionally, cotton producers spend nearly $200 million annually to reduce the damage from boll weevils and other cotton insects in boll weevil infested areas (fig. 1). The boll weevil is directly responsible for substantial yield losses on about 7 million acres of cotton. Important indirect losses also occur, due to the destruction of beneficial insects and the increased insecticide resistance in the bollworm and tobacco budworm resulting from insecticides applied to control the boll weevil.

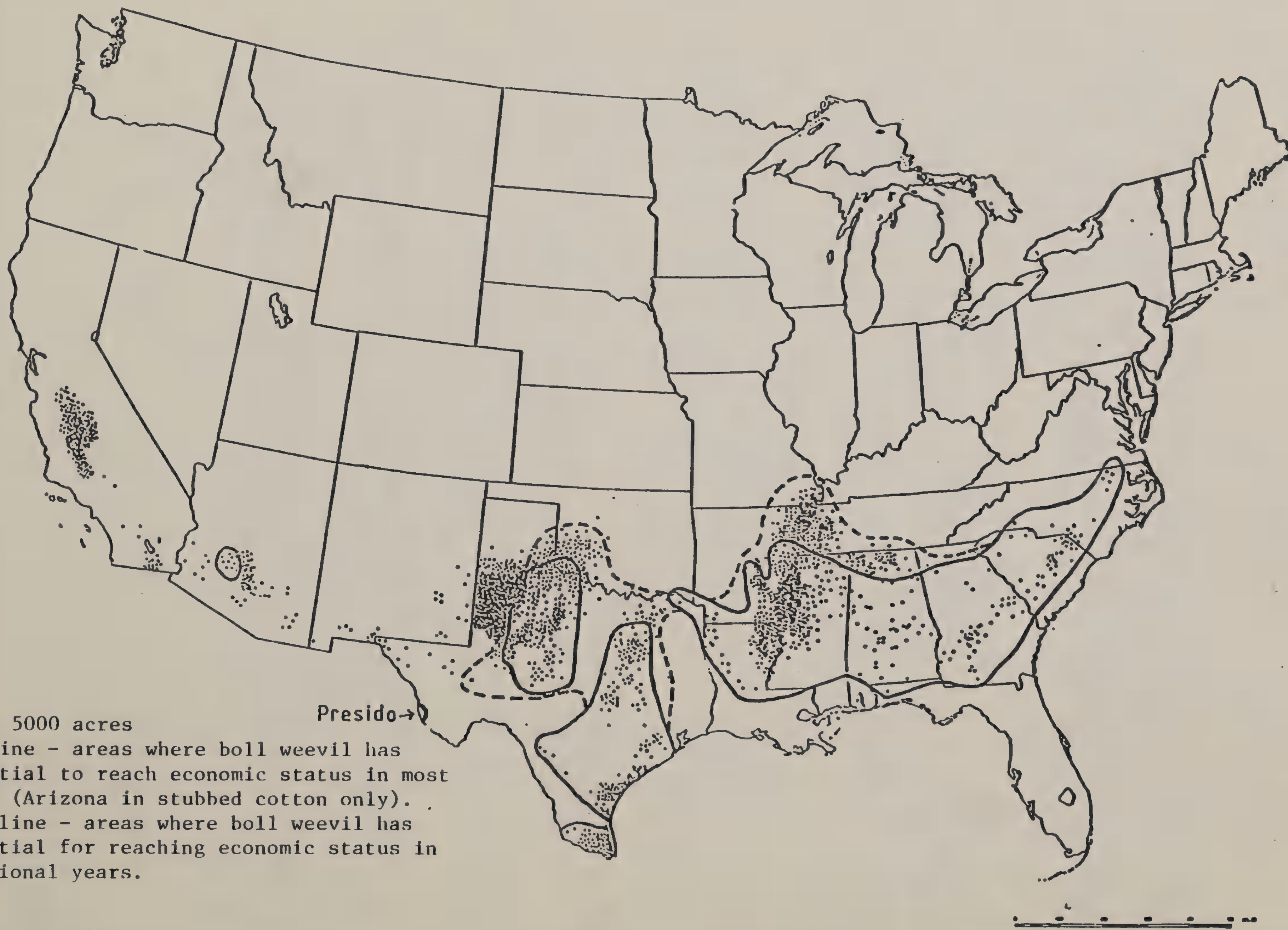
The substantial quantities of insecticides used in cotton production pose environmental concerns as well. Repeated application of insecticides can lead to an accumulation of residues in the environment which are potentially dangerous to some species of fish and wildlife. Some insecticide residues are accumulated biologically in the food chain and may be harmful to human health.

Evolution of Technology

In view of the economic and environmental problems posed by the boll weevil, and in recognition of the technical and operational advances in boll weevil management, a pilot project was established in 1971 in south Mississippi "to determine if it was technically and operationally feasible to eliminate the insect by properly integrating the use of various techniques" (2).

The conclusion of the Technical Guidance Committee for the Pilot Boll Weevil Eradication Experiment was that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States with techniques that are ecologically acceptable (2, p. 18). This conclusion was not accepted by a significant number of entomologists, some of whom questioned eradication as a goal and others who believed that the techniques needed improvement. Nevertheless, the pilot test led to the development of an overall plan to eliminate the boll weevil from the United States (2).

1/ Underscored numbers in parentheses refer to references listed at the end of this report.



Legend:

1 dot = 5000 acres
Solid line - areas where boll weevil has potential to reach economic status in most years (Arizona in stubbed cotton only).
Dashed line - areas where boll weevil has potential for reaching economic status in occasional years.

Figure 1. United States cotton acreage, average 1974-78, and distribution of boll weevil infestation. (5)

Coincident with the pilot test results, legislation gave further impetus to eradication as a component of an insect management program. The Agricultural and Consumer Protection Act of 1973 states that the "...Secretary is authorized and directed to carry out programs to destroy and eliminate cotton boll weevils in infested areas of the United States...if the Secretary determines that methods and systems have been developed to the point that success in eradication of such insects is assured" (3). This authorization has not been superceded.

The prevailing viewpoint following the south Mississippi trial was that the results failed to demonstrate conclusively the technical and operational feasibility of eradication. Subsequently, USDA held a series of conferences with State and Federal research, extension, and regulatory officials and producers to determine interest and willingness to participate in a beltwide program. In these discussions, a 3-year eradication trial was proposed to further demonstrate and refine the effectiveness of suppression measures. The trial also would test the logistics and detailed execution of the eradication technology on a large operational scale. Further discussions resulted in selection of a Boll Weevil Eradication (BWE) Trial in North Carolina and Virginia and a concurrent Optimum Pest Management (OPM) Trial in Mississippi, the latter to evaluate an alternative extension areawide insect management system.

Policy and Mission

The testing and evaluation of improved cotton insect management programs is consistent with USDA policy on pest management. "It is the policy of the U.S. Department of Agriculture to develop, practice, and encourage the use of integrated pest management methods, systems, and strategies that are practical, effective and energy-efficient.....with the least hazard to man, his possessions, wildlife and the natural environment." 2/ The evaluation of alternative programs that have the potential to reduce insecticide use and production costs and to increase lint yields is supportive of "a principal mission of the Department...to assure an adequate supply of high quality food and fiber and a high quality environment for the American people". 2/

Objective and Scope of Evaluations

The overall objective of the trials and evaluations was to provide information to the Secretary of Agriculture, Office of Management and Budget, Congress, producers, scientists and the public to simplify the choice of a cotton insect management program throughout the boll weevil-infested areas of the Cotton Belt.

Two large-area cotton insect management trials, Boll Weevil Eradication (BWE) and Optimum Pest Management (OPM), were initiated in 1978 in North Carolina and Mississippi, respectively. The main focus of the technologies tested in the trials was management of the boll weevil. Concurrently, a comprehensive biological, economic, and environment evaluation was initiated to critically

---

2/ Sec. Memo No. 1929, "U.S.D.A. Policy on Pest Problems" Dec. 12, 1977

evaluate the trials and to assess the potential impacts of regional implementation of the technologies tested in the trials, as well as other proven insect control technologies (4).

This report discusses the technical and operational success of the Boll Weevil Eradication and the Optimum Pest Management trials. It also includes a discussion of the feasibility of implementating the technologies tested throughout weevil infested areas of the Cotton Belt. Six boll weevil/cotton insect management programs are defined, followed by estimates of the public costs which would be required for implementation. Insecticide use data and lint yields are shown, as estimated by the Delphi approach. The results of the economic and environmental evaluations are presented. The six beltwide programs are analyzed in terms of their relative ranking on key biological, economic, and environmental variables. The final section discusses some issues beyond the scope of the evaluations.

TECHNICAL AND OPERATIONAL FEASIBILITY

Two large-area boll weevil/cotton insect management trials were conducted for 3 years, beginning in 1978. These trials demonstrated the technical and operational feasibility of eradicating an established boll weevil population from a specified geographic area or eliminating the need for in-season boll weevil treatment by suppressing the weevil population. Based on the success of the trials and previous research and experience in managing cotton insects in other areas, beltwide boll weevil eradication and optimum pest management programs were considered technically and operationally feasible. Additionally, the trials provided data that were useful in estimating the beltwide biological impacts of implementing these and other programs.

Optimum Pest Management Trial (5,6)

The OPM trial was implemented by the Mississippi Cooperative Extension Service in Panola County, Mississippi, with grower, State, and Federal support. The objective of the OPM trial was to test the technical and operational feasibility of an areawide voluntary cotton insect management program with incentives.

The 3-year trial was conducted on 32,000 to 40,000 acres of cotton. Incentives to encourage grower participation included government payments for applications of insecticides in late season to reduce populations of overwintering boll weevils. Growers who participated were required to see that their cotton was inspected, i.e., scouted weekly, and that a report was filed with extension personnel. Additional educational services and technical assistance were provided by extension pest management specialists who were employed to support the trial and who resided within the trial area.

The procedures or program components used in each of the 3 years in the trial included annual use of pheromone traps for monitoring populations of boll weevils; pheromone and light traps for monitoring populations of bollworms and budworms; application of insecticides in early season at the time pinhead size squares were present, if needed; scouting; in-season insecticide control of cotton insects by producers; four applications of insecticide in the fall to reduce numbers of overwintering boll weevils at no expense to growers; and voluntary destruction of stalks when harvest was completed before frost.

About 75 percent of the acreage was scouted by private consultants, 15 percent by producers, and 10 percent by a service provided by the Panola County Extension Pest Management Society.

The four late season applications of insecticide treatments used in 1978 and 1979 reduced numbers of boll weevils taken in traps during 1979 and 1980 by 78 and 94 percent, respectively, compared with trap catches in a Current Insect Control (CIC) area in Pontotoc County. These applications of insecticides

seemed to have little, if any, adverse effect the following year on the populations of natural enemies of bollworms and budworms. In addition, there was no need for in-season applications of insecticide for control of the boll weevil, and the number needed to control bollworms and budworms declined.

Finally, a review of yield records available for Panola County for a number of years indicated that OPM may have increased yields during the 3 years and a simulation model indicated that increases of 18 to 22 pounds of lint per acre might be expected if OPM were implemented for the entire State.

Thus, the suppression of diapausing boll weevil populations with four insecticide treatments in the fall eliminated the need for in-season control of the boll weevils and reduced the number of treatments for control of bollworms and budworms. The OPM trial, therefore, was appraised a biological and technical success.

An essential element in the biological success of the OPM trial was a high percentage of growers and acreage participating in fall diapause to eliminate areas for reinfestation. Panola County cotton producers participated at the rate of 98.7 percent, 99.6 percent, and 99.7 percent for 1978, 1979 and 1980, respectively.

Operationally, the OPM trial was conducted with a minimum of problems. The knowledge of the local cotton community was incorporated with the techical assistance of extension personnel. The OPM trial is an excellent example of agricultural consultants and public employees working together to benefit the producer. Twelve private consultants worked in Panola County during the OPM trial. They checked 75 percent of the cotton acreage. Consultants met regularly with OPM personnel to share data and discuss mutual problems.

Boll Weevil Eradication (BWE) Trial (5,7)

The BWE trial was conducted by the Animal and Plant Health Inspection Service, USDA, with grower, State, and Federal support. In December 1976, growers in North Carolina affirmed, through a referendum, their approval for the trial to be conducted and to pay 50 percent of the costs. Approval for the trial in Virginia was obtained through a public hearing. In 1976 the General Assembly of North Carolina funded the North Carolina Department of Agriculture to support 25 percent of the trial's operational costs. The Virginia Commissioner of Agriculture and Commerce was able to provide sufficient funds for supporting 25 percent of the costs in Virginia without special appropriation. Costs of the BWE trial were shared by participating groups as follows: cotton producers, 50 perccent; USDA-APHIS, 25 percent; and North Carolina Department of Agriculture and Virginia Department of Agriculture, 25 percent.

Funding by Congress for the USDA portion of the BWE trial costs was received during FY-1977 through FY-1980. FY-1977 funds were used to establish and support the evaluation and research and development support activities. Appropriations in FY-1978 through FY-1980 supported the cooperative trial.

The objective of the trial was to determine whether eradication of an established population of boll weevils from a specified geographic area was technically and operationally feasible. The boll weevil was reported in this area in 1922, and has infested cotton there ever since.

The 3-year trial was conducted on 16,000 acres of cotton the first year and on 34,000 acres in the third year. The trial area was divided into two main areas, the evaluation area and the buffer area. In addition, records were maintained separately for Chowan County, which was in the evaluation area but isolated from all other cotton in the evaluation area by about 30 miles and from other infested cotton by about 120 miles. Extensive monitoring by pheromone traps and field inspections was conducted throughout the trial area (table 1). Similar monitoring also was done in an area outside of, but adjacent to, the BWE trial.

During year 1 of the 3-year trial, insecticides were applied in season to protect the crop and in late season to reduce populations of overwintering weevils. In year 2, several suppression components were employed, including limited use of diflubenzuron (Dimilin ®), release of sterile weevils (139 per acre each week for 4 weeks, i.e., a total of 11.2 million), and use of in-field pheromone traps.

During year 3, the goal was the detection of remaining weevils and the complete elimination of any that had survived (i.e., "native") or had been reintroduced from outside the evaluation area.

At the start of the BWE trial, the population of weevils was relatively low because of the intensive use of insecticides for control of bollworms and budworms and two successive unusually cold winters in the years preceding the trial. On the basis of an estimated trap efficiency and assumed mortality due to fall applications of insecticides, four weevils/100 acres or a total of about 490 weevils were calculated to remain on 12,485 acres of cotton near the end of year 1. During the second year, after the fall applications of the first year, an estimated 15-25 overwintered weevils emerged in the evaluation area. This estimate was supported when intensive trapping resulted in the capture of only seven overwintered "native" boll weevils. Two boll weevils also were trapped in fall traps in year 2; but since no boll weevils were captured in traps placed in cotton fields, reproduction of weevils within the evaluation area apparently did not occur.

During year 3 of the BWE trial, a single headless boll weevil was found during the first trap inspection in May; this was believed to have carried over the winter in a stored trap. Also, four weevils were captured between August 18 and October 28 in migration traps just inside the evaluation area but distant from cottonfields. These weevils were considered to be migrants from outside the evaluatior area on the basis of observed patterns of dispersal of boll weevils from infested cotton. Then, beginning September 11, one pupa and nine adult boll weevils were detected in a clump within a single field near the northern limits of the evaluation area. These weevils were believed to be

Table 1--Boll weevil trapping logistics and results for indicated periods and areas (cottonfield traps only)

	No. traps 1/			No. boll weevils detected			Avg. no. boll weevils/1,000 traps		
	Spring hibernation traps	Summer in-field traps	Fall border traps	Spring hibernation traps	Summer in-field traps	Fall border traps	Spring hibernation traps	Summer in-field traps	Fall border traps
Evaluation area									
1977	-	-	450	-	-	1,354	-	-	3,008.89
1978	3,383	-	2,293	199	-	1,009	58.82	-	440.03
1979	14,676	30,244	19,399	7	0	2	0.48	0	0.10
1980	16,564	26,263	22,701	1	0	10 2/	0.6	0	0.44
Buffer area									
1977	-	-	-	-	-	-	-	-	-
1978	713	-	678	67	-	37	93.97	-	54.57
1979	3,722	4,253	3,864	38	70	867	10.21	16.46	224.38
1980	4,031	5,549	5,087	117	133	11,608	29.02	23.96	2,281.89
Chowan county									
1977	193	193	824	22	26	170	113.9	134.7	206.3
1978	760	-	760	10	-	0	13.2	-	0
1979	420	1,458	1,293	0	0	0	0	0	0
1980	1,117	1,548	1,548	0	0	0	0	0	0
Outside area 3/									
1978	-	-	95	-	-	136	-	-	1,442.00
1979	712	-	1,541	3,640	-	117,874	5,112.36	-	76,504.87
1980	1,559	-	1,512	78,478	-	483,260	50,338.68	-	319,616.40

1/ Spring hibernation, summer in-field, and fall border traps were generally operated April 15 - July 30, July 15 - August 30, and September 1 - November 1, respectively..

2/ All 10 boll weevils detected were in one localized portion of a single cottonfield. An additional 4 boll weevils were captured in migration traps located away from cottonfields in the southern edge of the evaluation area. Total detections in the evaluation area in 1980 = 15 boll weevils.

3/ Outside area constituted a survey of sample cottonfields within a 100-mile area south from the outer buffer area boundary. South Carolina trapping coordinated by Clemson University, Clemson, S.C.

the offspring of an introduced gravid female. This infestation was eliminated by intensive trapping and cultural practices. Traps were placed there at a very high density and operated until November 15, a period of 7 weeks. No additional weevils were captured.

No boll weevils have been detected in the isolated county (Chowan County) within the evaluation area since June 1978, and no infestations of weevils were detected in the evaluation area between October 1978 and September 1980. In view of the expected rate of increase of a boll weevil population and the sensitivity of pheromone traps, statistical analysis indicated a probability of at least 0.9983 that the occurrence of a reproductive population would have been detected during this period. Review and analysis of relative data indicate that the boll weevils found in the evaluation area after June 1979 were "reintroduced" weevils. Therefore, "native" boll weevils were eradicated from the evaluation area.

Overall, in the North Carolina BWE trial, the average number of insecticide applications decreased in the evaluation area and in the associated Current Insect Control (CIC) area in North Carolina by 88 percent and 25 percent, respectively, as compared with the 1974-1977 pretrial averages.

Yield changes due to the BWE trial were difficult to estimate because of highly variable weather during the 3 years. However, there is evidence that small increases in yields were an indirect effect of the trial.

Thus, with concurrent conservative use of insecticides and apparently increasing populations of natural enemies of bollworms and budworms, the eradication of a well established boll weevil population was demonstrated to be a biological as well as a technical success.

The logistics of eradication of the boll weevil in North Carolina presented no major problems. Adequate personnel were available to conduct the trial.

Beltwide Implementation (5,6,7)

The OPM and BWE trials were judged by the Biological Evaluation Team to be technical and biological successes, i.e., in the OPM trial, no in-season applications of insecticide were required for boll weevil control and, in the BWE trial, "native" boll weevils were eradicated from the evaluation area with a probability level of 0.9983.

The Biological Evaluation Team also concluded that the following procedures used in both trials should be generally acceptable beltwide: (1) at least 99 percent participation by producers, i.e., total population management, (2) more intensive monitoring with traps and by field inspection, (3) elimination of the use of broad-spectrum insecticides for in-season control of boll weevil, (4) conservation of populations of beneficial insects, and (5) reduction in amounts of insecticide used to control bollworms and budworms.

Some uncertainties are associated with beltwide implementation of current control practices, especially in regard to the adequacy of proposed barrier zone(s) set up to prevent reentry of boll weevils following eradication. Also, the survey and suppression technologies would likely require modifications in certain areas of the Cotton Belt because of the existence of different environments and cultural practices. However, if the various technologies used in the trials are properly applied, they are expected to be just as effective in other weevil-infested areas of the Cotton Belt, with the possible exception of south Texas.

Operational feasibility also is a critical factor in determining which insect management program could be implemented beltwide. A minimum of logistical and personnel problems were encountered in the two trials. Operational procedures would vary if the programs were implemented beltwide to conform with legal and institutional requirements of the States and if they incorporated the production practices and knowledge of the local cotton communities.

The organization of proposed programs and the availability of technicians must be considered in determining the viability of the programs. The current pest management system in place in all cotton States provides a framework for building the more complex OPM structure. Additional employees could be integrated into this framework easily. Many agricultural students and graduates and persons with science degrees can be trained to perform technical services. About 2 years would be required to recruit and train technicians from this manpower pool to carry out the proposed OPM programs.

All programs for cotton insect management should be flexible enough to capitalize on the expertise of private consultants. Provisions must be made for sharing information, contractual services, etc., to promote their cooperation. The highest concentration of agricultural consultants is in the Mid-South, followed by Texas and California. There are few consultants in the remainder of the Cotton Belt, but their numbers are increasing.

Based on the experience in the OPM trial and assuming funds will be available to fully reimburse producers for diapause treatments and pinhead square treatments as needed, a beltwide OPM program is considered operationally feasible. Utilizing the experience in the BWE trial and assuming cooperation of the State Departments of Agriculture in the boll weevil-infested States, ASCS, Extension Services, and growers (via referendum), a beltwide eradication program also is considered operationally feasible.

PROGRAM DEFINITIONS AND PUBLIC COSTS

Acceptable and well understood definitions of beltwide boll weevil/cotton insect management programs were required to estimate public costs of implementation and farmers' costs of insecticide use and lint yields associated with each program. A Program Definition and Cost Facilitator Group specified guidelines and coordinated the review of definitions and the estimation of public costs of beltwide programs (8). The development of final program definitions and public costs, however, remains the primary responsibility of the Science and Education Administration-Extension Service (SEA-ES) and Animal and Plant Health Inspection Service (APHIS).

Program Definitions

Six beltwide boll weevil/cotton insect management programs were defined and approved by SEA-ES and APHIS personnel in consultation with Optimum Pest Management Regional Extension Education Advisory Committee (OPMREEAC), the Overall Evaluation Team, and the Facilitator Group. The program definitions are:

- Current Insect Control (CIC) assumes insect control as now practiced by producers ranging from no control to intensive treatment with insecticides. Current insect control implies a continuation of extension education and technical assistance at the present level of funding.

- Optimum Pest Management with Continuing Incentive Payments for Boll Weevil Management (OPM-I) would consist of two major insect management options, whichever is most applicable for a particular area. Additional extension personnel and support would be required to implement both options. One option, Optimum Pest Management (OPM), would utilize the boll weevil/cotton insect management practices that were tested in the Mississippi trial with emphasis on diapause and pinhead square treatments, as needed, and full reimbursement for the cost of these treatments. In all areas where the diapause strategy could not be implemented or where it is not needed, an alternate option, Modified Optimum Pest Management (MOPM), would be followed. It would utilize, if applicable, all the practices tested in the Mississippi trial except the organized areawide diapause strategy, but may include voluntary diapause treatments by individual producers.

  In areas having potential for moderate-to-heavy infestations of boll weevils, the OPM option would be implemented where effective. Diapause and pinhead square treatments would be specified as recommended technology. The criterion for an effective program is to maintain the midseason population of boll weevils below treatment levels on 90 percent or more of the acreage prior to onset of *Heliothis* pressure. Growers would be reimbursed for boll weevil diapause and pinhead square treatments at such a level and over sufficient treated acreage to achieve an effective program.

As an example, OPM in Mississippi would: (1) use grandlure baited traps as survey tools; (2) urge producers to plant cotton within recommended dates; (3) recommendation and reimburse producers for pinhead square applications, if needed; (4) scout all cotton by commercial consultants, grower organizations, CES employees, or trained producers; (5) urge producers to follow CES recommendations for in-season control of boll weevils and other cotton insects; (6) reimburse producers for boll weevil diapause treatments, if needed; and (7) urge producers to destroy stalks, if harvested prior to frost. Consultant and grower organizations would be involved, with CES providing information on recommended insect control practices.

However, in areas, if any, where the required acreage for an effective program could not be reached with the OPM option or where boll weevil infestations are historically light and usually do not reach treatment levels, the Modified Optimum Pest Management (MOPM) option would be implemented. This option implies that the diapause and pinhead square technology either could not be adopted on a sufficient percentage of the cotton acreage for an effective areawide OPM option or it would not be needed because of the low population levels of boll weevil. The objective of MOPM is to reduce the number of unnecessary in-season treatments for boll weevil and other cotton insects through effective scouting and monitoring. Examples of areas where diapause and/or pinhead square treatments are not commonly needed include north Alabama, some areas in the Mississippi Delta, Upper Concho area of Texas, and north Oklahoma.

To implement both options under the OPM-NI program, additional extension personnel and funds would be required to provide technical information and educational guidance in the management of boll weevils and other cotton insects. All available proven technology may be applied in implementing this program. Use of the technology recommended and participation in this program would be voluntary on the part of the grower. From 1 to 3 years may be required to fully implement this program, depending on cotton acreage and availability of staff. The acreage that one entomologist can handle will vary because of the location and intensity of cotton acreage as well as historic patterns of insect management problems.

- Optimum Pest Management with Phased Incentive Payments for Boll Weevil Management (OPM-PI) includes the same program components including personnel and funds as OPM-I except that incentive payments for diapause and pinhead square treatments would be phased out over time as follows:

1st year:	Same as OPM-I, 100 percent of needed treatment
2nd year:	75 percent of needed treatment
3rd year:	50 percent of needed treatment
4th year:	No incentive payment

The logic in evaluating this program is that in some areas an incentive may serve to demonstrate the technical and economic feasibility of diapause and pinhead square treatments and that growers may continue the use of these practices. If the required acreage for an effective diapause/pinhead square option could not be maintained after payments are phased out, the MOPM option would be implemented.

- <u>Optimum Pest Management with No Incentive Payments for Boll Weevil Management (OPM-NI)</u> is the same as OPM-I with the exception that no reimbursements to producers would be made for diapause or pinhead square treatments. If the required level of acreage could not be reached, the MOPM option would be established and the diapause/pinhead square technology would not be implemented on an areawide basis.

- <u>Optimum Pest Management with No Incentive Payments and with Boll Weevil Eradication (OPM-NI-BWE)</u> includes eradication of the boll weevil as a major component. The beltwide eradication component would use the technology proven by the North Carolina trial and ongoing research. However, it does not need to be a replication of the North Carolina trial.

  Boll weevil eradication would begin in the Southeast and proceed west through eight separate zones, followed by the maintenance of a buffer zone between the United States and Mexico to inhibit reinfestation. To insure efficient implementation of this program, OPM-NI would be implemented beltwide 1 year prior to the initiation of eradication. MOPM practices for the control of other insects would be in place during and following eradication. The major components of the program to eradicate the boll weevil from a designated zone are:

  (1) Prior to eradication, the voluntary program with no incentive payments to producers (OPM-NI) would involve information and education, organization of producers and encouragement of producers to follow recommended insect control practices.

  (2) During the first year of eradication, growers would be responsible for in-season control of all insects, including boll weevils. Growers would be urged to follow recommendations for all cotton insects. Beginning in early September (depending on area and weather) APHIS would initiate a boll weevil eradication program with diapause treatments of boll weevils, using guthion, malathion, or other recommended insecticides, as needed. A range of 5-10 treatments is projected to be required on all acreage in infested areas.

  (3) During the second year of eradication, APHIS would monitor and control incipient boll weevil infestations by the use of sterile weevils, Dimilin®, and organophosphorous insecticides, as needed. Growers would be urged to follow recommended practices for control of other insects.

  (4) During subsequent years, growers would continue with MOPM practices for the control of other insects in a weevil-free environment, while regulatory

agencies would assume responsibility for routine surveillance of the areas cleared (trapping density of 1 per 200 acres) and the control of incipient boll weevil infestations. Following eradication, the Extension Service would continue to provide information to growers on how best to manage cotton insects in the absence of the boll weevil.

- <u>Current Insect Control with Boll Weevil Eradication (CIC-BWE)</u> also would include eradication of the boll weevil as a major supplement to the current cotton insect management program. The beltwide eradication component would use the technology proven by the North Carolina trial and ongoing research. The eradication component remains essentially the same as in OPM-NI-BWE, but there are no provisions for additional staffing or funding of CES programs prior to, during, or following eradication.

<u>Public Costs</u>

The pattern of estimated public costs for each of the beltwide programs varies considerably from initiation through full implementation (table 2 and fig. 2):

- The CIC and three incentive-related OPM programs would be funded through SEA-ES while the eradication programs, CIC-BWE and OPM-NI-BWE, would be jointly funded by SEA-ES and APHIS.

- CIC, the baseline program, is currently costing about $2.5 million annually and it would continue at that rate.

- The funding for the OPM-I program with continuing incentive payments would increase from about $6 million the first year to $36 million by the second year and remain at that level.

- The costs for OPM-PI would be similar to OPM-I during the first 2 years but would decline to $7 million by the fifth year.

- The OPM-NI program costs would increase to $7 million by the second year and continue at that rate.

- Compared with OPM-NI, about $1 million more would be needed under the OPM phased and full incentives programs during the first year to prepare producers for the areawide diapause strategy.

- With the eradication programs, OPM-NI-BWE and CIC-BWE, the costs rise to $94 million and $87 million, respectively, in the fifth year and decline to $8 million and $3 million by the twelfth and subsequent years depending on whether the OPM or CIC Extension support is provided. It would cost an estimated $460 million, including capital investments, during the 9 years to eradicate the boll weevil. If farmers share part of the eradication costs, public expenditures under the two eradication programs would be reduced.

Table 2--Annual public costs for beltwide boll weevil/cotton insect management programs 1/

Year	CIC	OPM-I	OPM-PI	OPM-NI	OPM-NI-BWE 2/	CIC-BWE 2/
	Million dollars 3/					
1	2.5	5.6	5.5	4.7	6.2	2.5
2	"	35.8	35.6	6.9	19.1	12.1
3	"	"	28.9	"	46.2	39.2
4	"	"	22.1	"	79.5	72.5
5	"	"	6.9	"	94.3	87.3
6	"	"	"	"	74.0	67.1
7	"	"	"	"	51.0	44.1
8	"	"	"	"	74.1	67.2
9	"	"	"	"	65.4	59.3
10	"	"	"	"	21.1	16.0
11	"	"	"	"	7.7	3.3
12	"	"	"	"	7.5	3.1
13	"	"	"	"	"	"
14	"	"	"	"	"	"
15	2.5	35.8	6.9	6.9	7.5	3.1

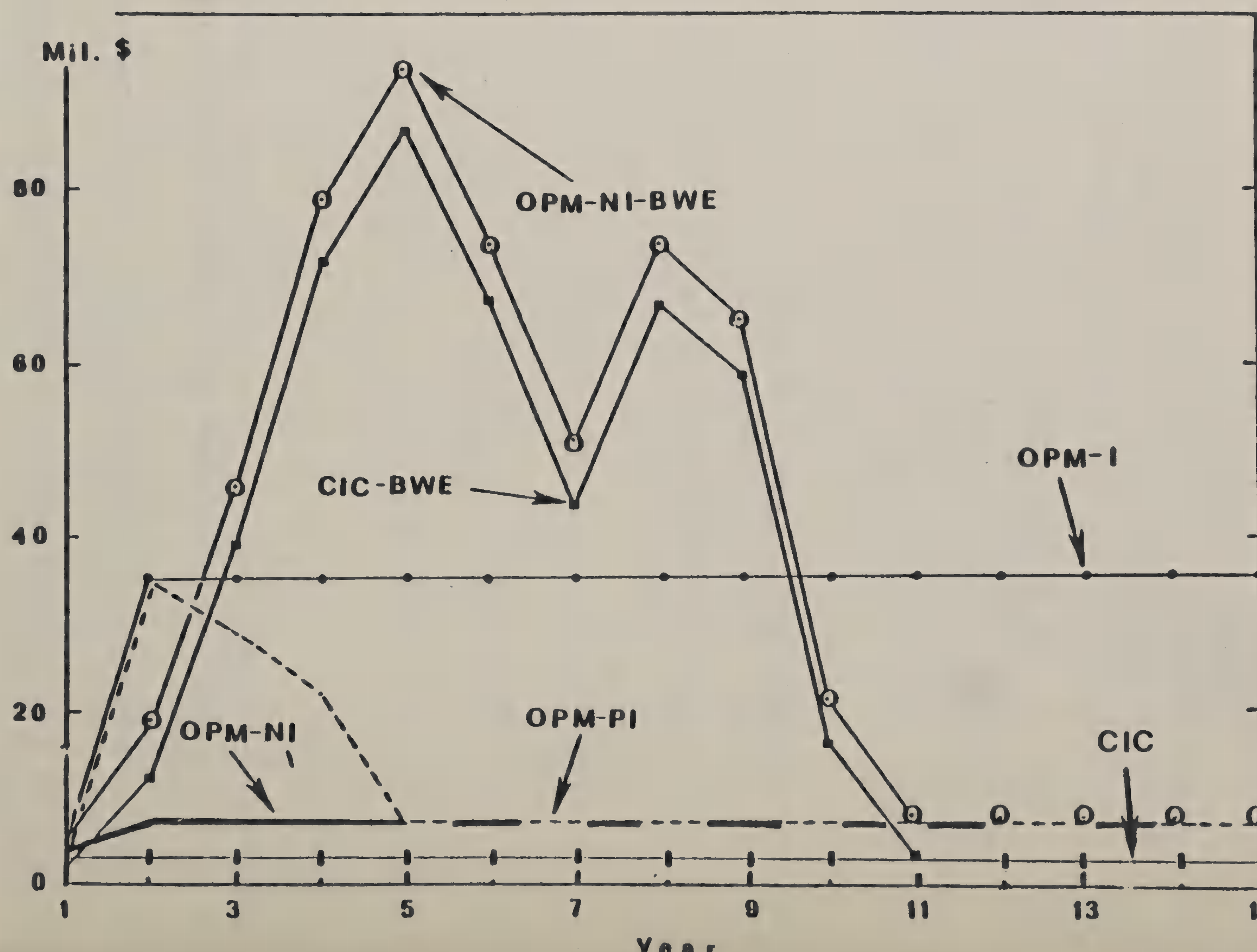
1/ The six programs are: CIC (Current Insect Control); OPM-I (Optimum Pest Management with Incentives); OPM-PI (Optimum Pest Management with Phased Incentives) OPM-NI (Optimum Pest Management with No Incentives); OPM-NI-BWE (Optimum Pest Management with No Incentives and with Boll Weevil Eradication); and CIC-BWE (Current Insect Control with Boll Weevil Eradication).

2/ Includes all eradication program costs as well as related OPM-NI and followup monitoring costs. Public costs would be lower than these amounts if farmers share some of the eradication costs.

3/ Assumes constant 1979 dollars and constant 1974-1978 average acreage.

Figure 2.

PUBLIC COSTS FOR BELTWIDE PROGRAMS



Validity of Public Costs Estimates

The benefit-cost analysis of beltwide boll weevil/cotton insect management programs rests heavily on the estimates of program costs. The extent to which these estimates are overstated or understated relative to other programs can affect the net benefits and benefit-cost ratio and subsequent choice of program. The cost base for CIC includes all Federal and State funds specifically directed at cotton insect control in the 11 State area. County extension agents were not included because they would be needed for pest management programs relating to all crops. If there were regional or county entomologists, their costs were included. The $2.5 million for CIC is a conservative estimate of the effort devoted to all cotton insect control, but its exact size is not important because the investment opportunities are viewed as being increments above a base situation.

The estimates of public costs for the OPM-I and OPM-NI-BWE programs are probably the most accurate because of the experience gained in the 3-year trials. Extrapolations across the 11-State area received several rounds of scrutinizing by Federal and State agencies to assure consistency between programs across States. The relatively low monitoring costs of $590,000 per year and no earmarked contingency cost for dealing with reinfestations after eradication may result in cost overruns, but these items do not become important cost factors until 10 years have elapsed. The monitoring activity would have to be underestimated by several magnitudes before it would affect the economic ranking of the programs.

The OPM-NI and OPM-PI program costs were simple derivatives of OPM-I. As such, the costs are estimated with mathematical precision.

The cost of the CIC-BWE program is probably underestimated since the eradication component is costed at the same level as OPM-NI-BWE. However, a more precise estimate would be of very little value in making a program choice. The benefit-cost ratios of the two eradication programs are similar -- 18:1 for CIC-BWE, 17:1 for OPM-NI-BWE. The additional extension personnel would appear to be cheap insurance to help achieve eradication.

BELTWIDE BIOLOGICAL ESTIMATES

The Delphi, a method for systematic collection of information from experts, was modified to estimate biological data required for the the economic and environmental analysis of beltwide boll weevil/cotton insect management programs (9). Cotton insect management and crop production experts projected the insecticide use patterns and cotton lint yields that would result under alternative insect management options in 32 weevil infested subregions of cotton production (fig. 3). These data were used to estimate average insecticide use and costs and cotton lint yields of current insect control (CIC) and five potential beltwide boll weevil/cotton insect management programs.

Insecticide Use and Lint Yields

Total changes in insecticide use and lint yields from CIC for the five new programs for the boll weevil infested portion of the Cotton Belt are shown below:

Insect management program	Acre treatments w/insecticides	Total producers' insect management costs	Total cotton lint production
	Million acres	Million dollars	Million pounds
CIC (baseline)	35	191	2,890
Changes from CIC:			
OPM-I	-1	-44 (-17)1/	117
OPM-PI	-4	-21	101
OPM-NI	-4	-21	101
CIC-BWE	-10	-47	116
OPM-NI-BWE	-11	-54	155

1/ The total reduction in insecticide costs would be only $17 million since producers would be reimbursed with public funds for an additional $27 million for fall diapause and overwintering weevil treatments.

Insecticide use and costs, and lint yields vary across cotton production regions (table 3 and fig. 4). Projected yield increases from CIC are generally of greater magnitude in the more western subregions than in the Mid-South and Southeast. Changes in insecticide use and the producers' cost of insect control, between CIC and OPM-NI-BWE, range from an estimated 33-percent increase in Missouri to a 90-percent decrease in Oklahoma.

Estimates of insecticide use and costs and lint yields represent farm-level impacts after full program implementation.

COTTON PRODUCTION REGIONS
(Boll Weevil-Infested Areas)

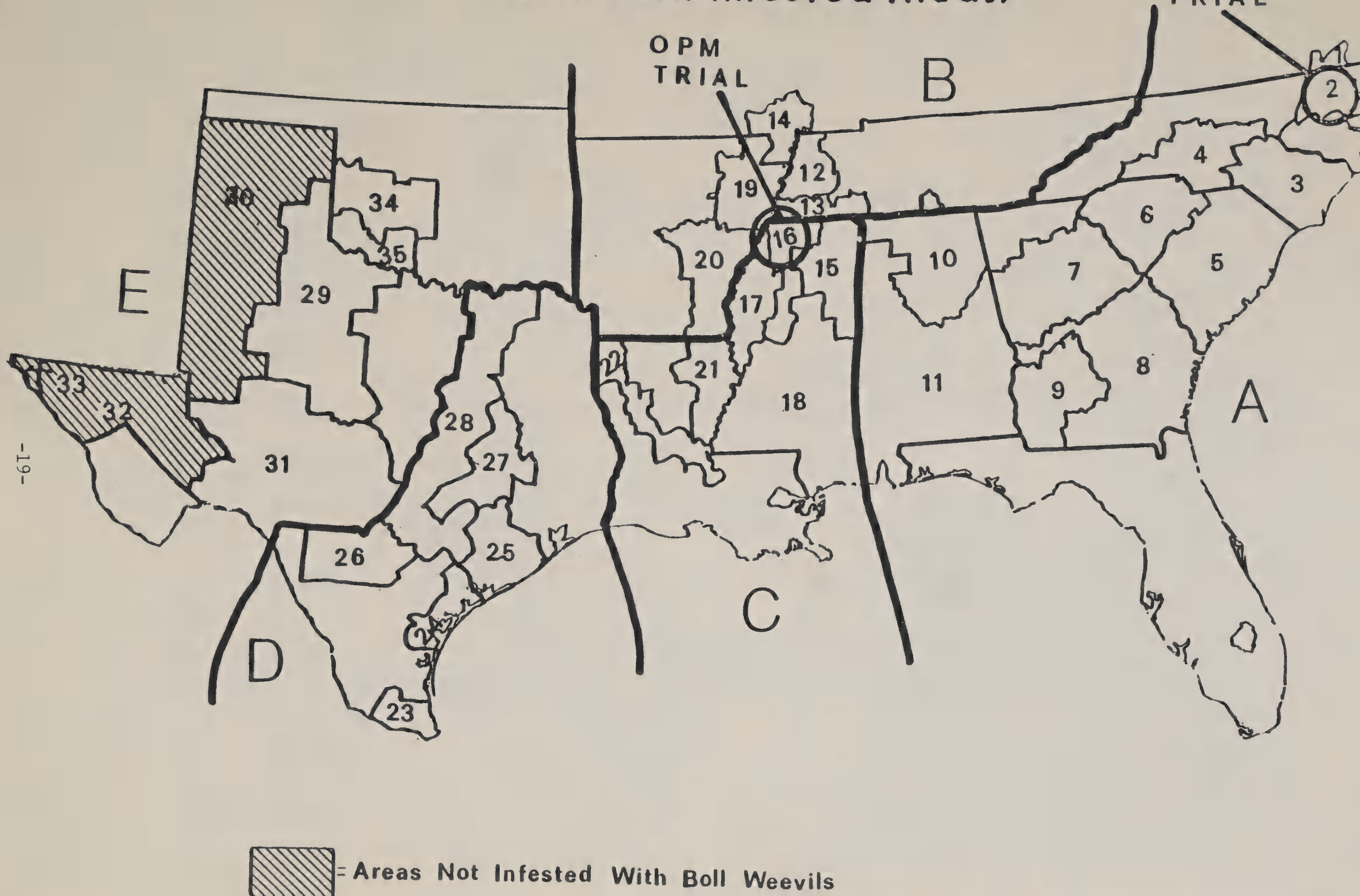


Figure 3

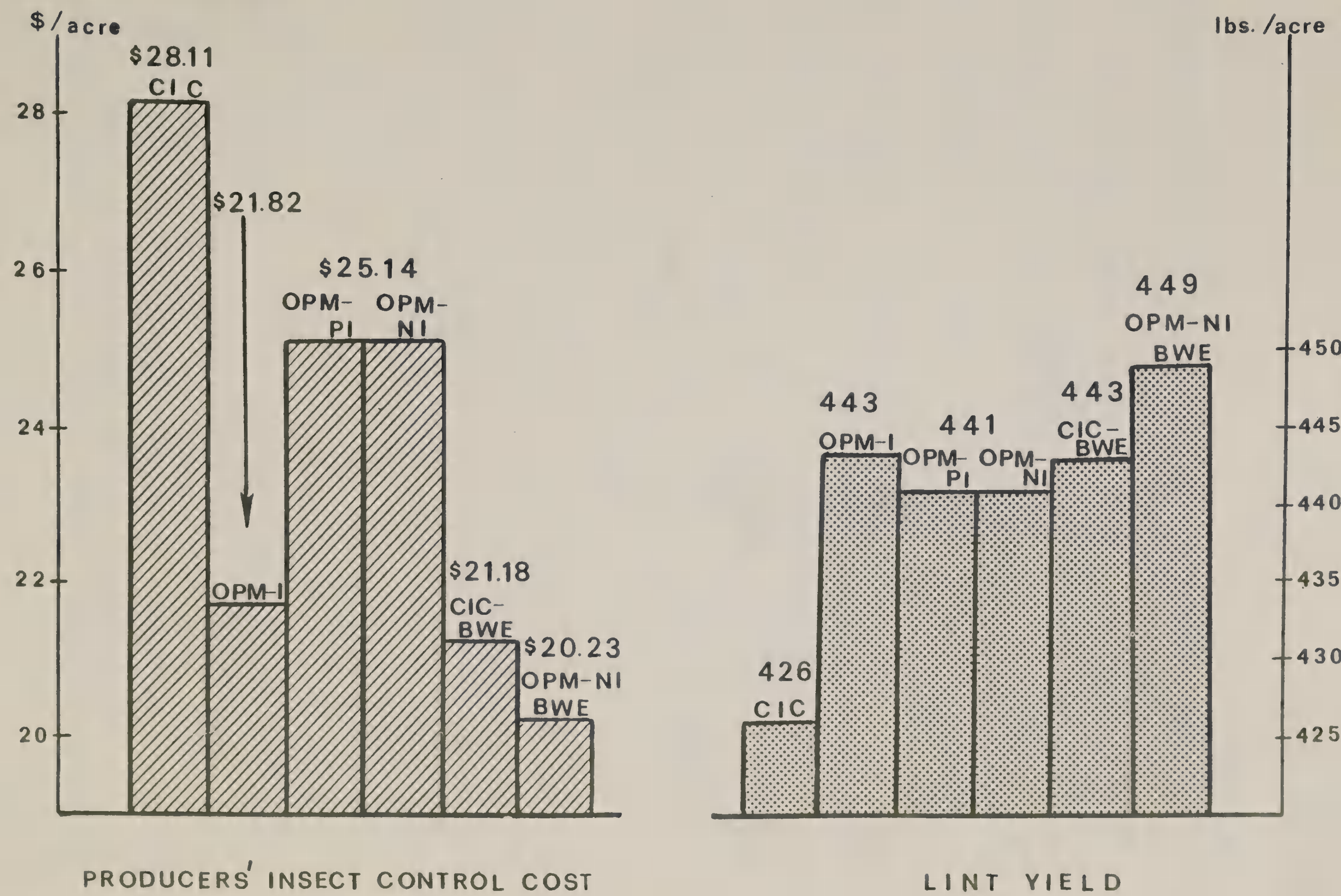
Table 3--Delphi-estimated total insecticide use, producers' insect control costs, and cotton lint production, by boll weevil/cotton insect management program (full implementation) 1/

Region	Management program	Average number of applications per acre	Acre treatments with insecticides (mil. acre treatments)	Total producers' insect control costs (mil. dols.) 2/	Total cotton lint production (mil. lbs.)
Region A	CIC	10.0	8.8	58	377
	OPM-I	11.2	9.7	53	394
	OPM-PI	10.0	8.7	57	394
	OPM-NI	10.0	8.7	57	394
	CIC-BWE	8.0	7.0	50	386
	OPM-NI-BWE	7.6	6.6	46	398
Region B	CIC	2.5	3.6	18	678
	OPM-I	3.1	4.4	14	686
	OPM-PI	2.6	3.7	17	686
	OPM-NI	2.5	3.6	17	686
	CIC-BWE	1.4	2.0	8	686
	OPM-NI-BWE	1.9	2.7	13	689
Region C	CIC	8.7	16.2	85	1,002
	OPM-I	7.9	14.7	66	1,011
	OPM-PI	8.0	14.8	78	1,011
	OPM-NI	8.0	14.8	78	1,011
	CIC-BWE	7.2	13.4	74	1,010
	OPM-NI-BWE	6.8	12.6	71	1,012
Region D	CIC	4.2	4.1	20	337
	OPM-I	3.4	3.3	10	375
	OPM-PI	3.3	3.1	14	365
	OPM-NI	3.3	3.1	14	365
	CIC-BWE	1.7	1.6	7	375
	OPM-NI-BWE	1.5	1.5	6	390
Region E	CIC	1.2	1.9	10	496
	OPM-I	1.1	1.8	2	541
	OPM-PI	0.7	1.1	4	536
	OPM-NI	0.7	1.1	4	536
	CIC-BWE	0.4	0.6	3	542
	OPM-NI-BWE	0.3	0.5	2	556
Total, boll weevil infested regions	CIC	5.1	35	191	2,890
	OPM-I	5.0	34	147	3,007
	OPM-PI	4.7	31	170	2,991
	OPM-NI	4.6	31	170	2,991
	CIC-BWE	3.6	25	144	3,006
	OPM-NI-BWE	3.5	24	137	3,045

1/ Assumes constant dollars and 1974-78 average cotton acreage.

2/ OPM costs do not include costs of diapause and overwinter control. Also farmers' share of eradication costs are not included.

Figure 4. Average producer insect control costs and lint yields by boll weevil/cotton insect management program, boll weevil-infested States.



Excludes Texas subregions 30, 32, and 33.

The Delphi

Beltwide consistent data bases of insecticide use and lint yields were not available from research literature. The development of beltwide data by simulation and multiple regression techniques was unsuccessful. Consequently, a modified Delphi approach was initiated. The Delphi is a systematic method to collect information from experts. In its conventional form, a panel of experts is surveyed through the mail, sent statistical summaries of survey results, and provided opportunities to revise individual responses based on averages and distributions of responses from the panel.

To estimate insecticide use patterns and lint yields, the Delphi was modified to allow for face-to-face interaction among expert panel members and consultation with a resource group. The resource group consisted of experts in various disciplines relevant to insect management and loss prevention who provided technical information, but did not interact in developing estimates.

Expert panels were formed by contacting State Experiment Stations and Extension Services, the chemical industry, a national private pest management consultants' organization, the State Departments of Agriculture in eleven boll weevil infested States, and the National Cotton Council. Each was requested to recommend experts to participate in the Delphi. Invitations to participate were extended to the individuals recommended. A total of 35 experts comprised of cotton research and extension entomologists, cotton specialists, chemical company representatives, and farmers, participated in the Delphi.

The Delphi consisted of three major rounds of data collection, review, and revision. A survey questionnaire was used to elicit expert estimates of factors that determine, on a per acre basis, subregional insecticide use, producers' insect control costs, and cotton lint resulting from the implementation of the six beltwide cotton insect management programs. Estimates were generated by the experts under the assumption that subregional cotton acreage and cotton price received by farmers were equivalent under all programs.

Validity of Delphi Estimates (9)

The Delphi data were collected in a systematic manner that provides ex-post substantiation of the process' results. An evaluation of the Delphi estimates showed that they generally fall within a range of available estimates from other partial sets of subjective or historical data. Participants' critique of the Delphi indicated general agreement that the subjective judgment of the expert Delphi panels represent the best available estimates of the average farm level impacts of a change in boll weevil/cotton insect management programs.

A degree of uncertainty must be attached to the Delphi estimates. This uncertainty arises from two sources. First, precise, scientifically determined

data are not available to substantiate the subjective judgments of the Delphi panels. However, this deficiency is the reason a Delphi approach was used.

Secondly, the standard deviations surrounding some Delphi average estimates, particularly those for lint yield changes in east Texas, show a relatively high variance of expert opinion among panel members. In recognition of this uncertainty, Delphi data were analyzed for sensitivity to changes. For example, the cotton econometric model was run using the cotton yields equal to 50 percent of those estimated by the Delphi panel. Total net market benefits changed but the relative ranking of the alternative programs was not changed.

Another concern regarding the Delphi estimates was whether they adequately recognized the boll weevil and bollworm-budworm interactions. Do the estimates reflect the benefits in the absence of the boll weevil in improved control of the bollworm-budworm complex? These interactions were explicitly addressed by the Delphi resource presentations, data collection process, and panel members. For example, the panelists, in estimating the impact of boll weevil eradication on cotton insect control practices, did not merely eliminate insecticides needed for weevil control. They also considered reduced insecticide requirements for worm control in recognition of the interaction between the pest species and the absence of the boll weevil in the eradication options. While it may be difficult for a reviewer to partition this interaction from all other impacts on insecticide use and yield changes, it was taken into account in the Delphi process. For example, the Delphi panel estimated that OPM-I would require 1 million fewer acre treatments with insecticide than CIC. However, this net reduction reflects an increase of about 4 million acre treatments for diapause control but a reduction of 5 million acre treatments mostly for weevils, weevil-worms and worms. Additionally, in comparison with CIC, the reduction of 10 and 11 million acre treatments with insecticide for CIC-BWE and OPM-NI-BWE, respectively, reflects even greater reduction in worm treatments. The distribution of insecticide treatments by pest complexes clearly indicate that the Delphi panels recognized the benefits of suppression or absence of weevils in their estimates of control of the worm complex.

ENVIRONMENTAL IMPACTS (11)

Three beltwide boll weevil/cotton insect management programs were evaluated for their environmental risks and hazards: Current Insect Control (CIC), Optimum Pest Management with Incentives (OPM-I) and Optimum Pest Management with No Incentives and with Boll Weevil Eradication (OPM-NI-BWE). Additionally, the environmental impacts of the two boll weevil/cotton insect control trials (1978-80) were evaluated.

The environmental evaluation was designed to address the concern that programs be conducted in ways that protect the Nation's ecological, cultural, and historic heritage as embodied in the intent of statutes, regulations, Executive Orders, and Secretary Memoranda. The evaluation recognized that decisions on insect control programs must be based on sound knowledge of (1) the crop protection chemicals and their potential hazard, (2) the patterns of transport throughout the environment and consequent exposure levels, (3) the effects of these calculated exposure levels upon biotic and abiotic interactions, and (4) the risk of these interactions upon sensitive environmental areas. The technical evaluation of the trial strategies and beltwide programs is presented within the context of these four considerations.

Trials (11)

The environmental evaluation of the trials utilized the methodology of BOLL-1, a local area evaluation model. Seven areas of impact (risk) were addressed with numerical indices of potential impact calculated for each. The seven areas of risk (offsite drift, human ingestion, research conflicts, endangered and threatened species, fish farms and hatcheries, wildlife, and aquatics) were combined into an overall index of impact for each of the trials.

This overall index Q, is defined as the weighted sum of the normalized indices. The following Q values were calculated for the 3 years:

OVERALL INDICES OF TRIAL STRATEGIES

Strategy	Trial years (Worst effect = 1000)		
	1978	1979	1980
Q_{OPM}	257	346	329
Q_{CIC-MS}	37	138	164
Q_{BWE}	160	24	12
Q_{CIC-NC}	219	294	171

The major dimension of impact which affected the overall index was human ingestion which, in turn, was directly affected by offsite drift. As the magnitude of insecticides was changed (i.e., more or less acres treated), the overall index also changed in the same direction.

These results indicated that the BWE strategy after the first year had the lowest overall index of impact in the trial areas. This was primarily attributed to the reduced amount of insecticides used, which resulted in a low human ingestion index.

Similarly, the pesticide residue monitoring data gathered in 1978, 1979, and 1980 indicated that none of the strategies had a high potential for adverse environmental impact in the trial areas.

Beltwide Programs (11)

The Environmental Evaluation of Pesticides (EEP) model was utilized to evaluate the environmental impact of the projected Beltwide Boll Weevil/Cotton Insect Management Programs. The beltwide evaluation consisted of a detailed analyses (including insecticide residue transport and distribution modeling) over three river basins, the Santee, Flint, and Red (fig. 5). A less detailed analysis over 12 additional river basins also was conducted (transport and distribution modeling was excluded). The 15 river basins were selected to represent the river basin evaluation across the Cotton Belt.

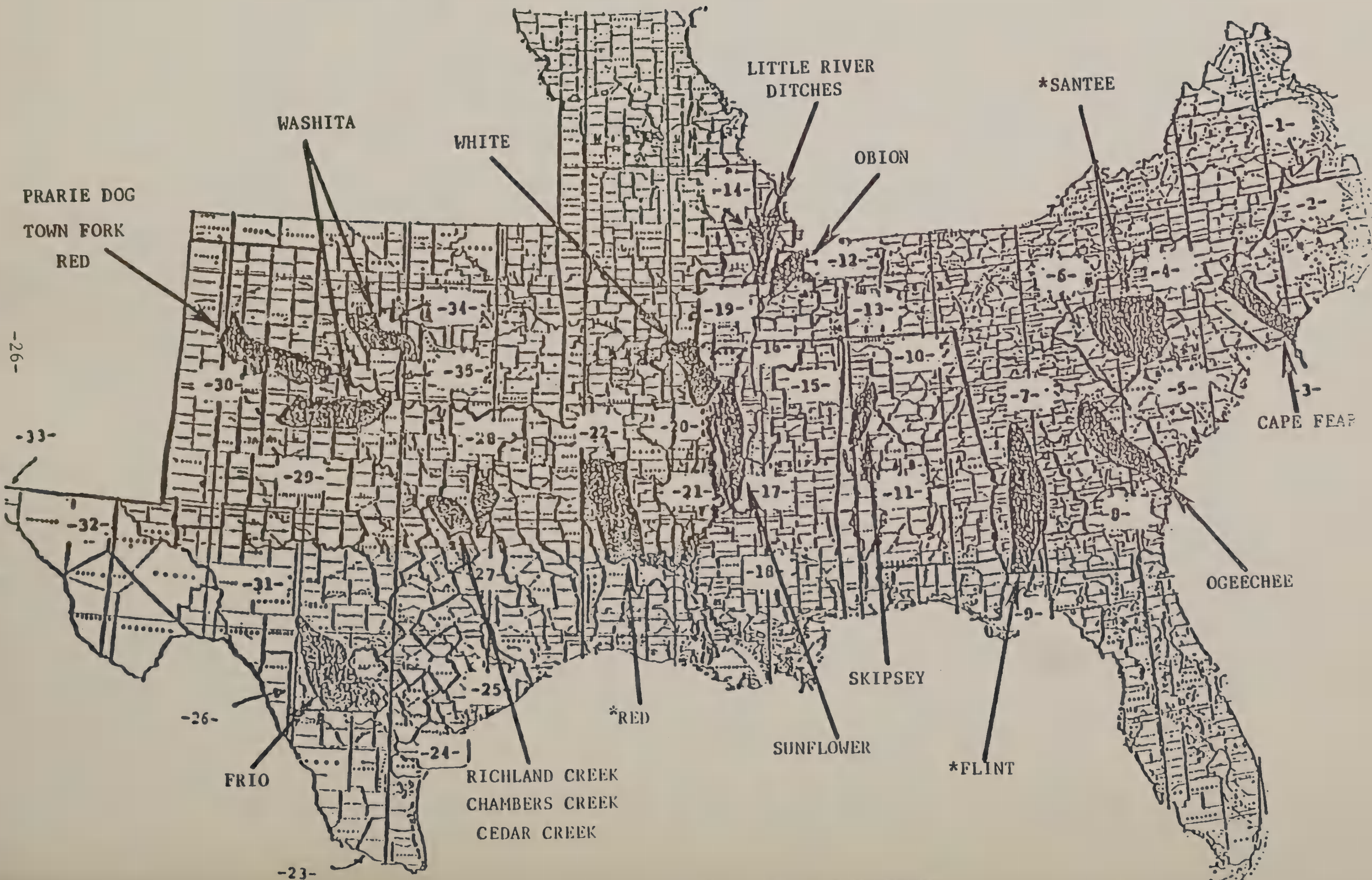
The beltwide evaluation of three cotton insect management programs was limited to major insecticides utilized, which were representative of four major categories of insecticides, i.e., organophosphates, carbamates, synthetic pyrethroids, and diflubenzuron, an insect growth regulator.

For the CIC program, the use of methyl parathion, methomyl, and permethrin was evaluated over the weevil-infested area of the Cotton Belt. No adverse effects would be expected in any of the river basins with respect to nontarget agriculture; that is, no adverse effects were projected upon livestock and poultry or upon crops. No significant acute or subacute impacts upon aquatic species were identified with any of the insecticides evaluated. No effects were foreseen in terms of adverse impact upon wildlife or human ingestion. The analysis showed that the very nature of the insecticides (e.g., rapidly degradable and nonlipophilic) negated such effects. There were no expected impacts upon endangered and threatened species in the other river basins.

The three insecticides evaluated for the CIC program were projected for the OPM-I beltwide program. They would be used in slightly lower amounts over a smaller acreage. The results of the analyses were essentially the same as

FIGURE 5

Locations of the 15 river basins evaluated for environmental impacts of alternative boll weevil/cotton insect management programs



with the CIC program over all river basins. However, given the smaller amounts of insecticides that would be applied, the degree of impact would be lessened to a commensurate degree.

The OPM-NI-BWE beltwide program projected the use of malathion, diflubenzuron, and azinphos-methyl. The beltwide evaluation of this program was based only on the first year of boll weevil eradication within any given area, representing the highest insecticide exposure or worst-case condition. As with CIC and OPM-I, no significant adverse environmental impacts were projected in any river basins. After the first year, fewer insecticides would be necessary for any given area in the OPM-NI-BWE program. Consequently, the potential of environmental risk after the program is fully implemented would be even further reduced.

There were no reports of expected impact in terms of research conflicts resulting from any of the three programs over any of the river basins studied. A potential existed for research conflict with respect to the BWE program because of its requirement that all cotton in the area be included in the program; however, no specific examples of potential impact were found via an informal survey of area researchers.

In terms of social perception, a very low percentage of those persons questioned were aware of the program or its components and they were concerned only with the technical feasibility of the beltwide implementation of a program. This reflects the fact that the vast majority of those who were aware of the program were engaged in cotton production related research.

The beltwide evaluation revealed only three potential environmental impacts. All should be easily mitigatable and, in fact, should not be affected at all if the selected beltwide program is properly administered.

- Because of the toxicity of the program insecticides to honeybees, bee colonies next to cottonfields could suffer losses unless moved to a safe distance.

- Endangered and threatened species could be jeopardized by a beltwide program. One such State-listed threatened beetle species, Myotrupes retuses, was identified in the Santee river basin. Habitats for these identified species should be mapped to ensure that such habitats are not inadvertently sprayed.

- A worst-case scenario indicated that populations of some small aquatic organisms in farm ponds or streams adjacent to cottonfields could be affected after insecticide application, followed by excessive runoff from heavy rains. Because of the short-lived nature of the program insecticides, these aquatic populations should recover rapidly.

Based on the technical analyses that addressed the environmental risks and hazards in the trial areas and selected river basins, no substantial adverse environmental effects would be expected from the CIC, OPM-I, or OPM-NI-BWE programs.

In general, a reduction of insecticide use in any program reduces the potential risk of adverse environmental effects and, thereby, tends to improve the quality of the environment. The benefit of insecticide reduction is that the capacity of the environment to respond to the exposure levels of chemicals is also improved. This implies that any cotton insect management program that reduces total insecticide load in the environment would likely improve the capacity of the environment to respond to insecticide pressure. Additionally, reduced use of insecticides and number of applications also reduce the exposure to applicators. This improved environmental capacity potential and reduced exposure to insecticide applications is a benefit of all proposed programs in terms of human health, aesthetics, and recreation.

Insecticide use (IU) indices were estimated for all programs using pounds (active ingredients--a.i.) of insecticides as a proxy:

Program	Pounds of insecticides used (a.i.) 1/		IU index
	Total Million pounds	Per Acre pounds	
CIC	34.0	5.0	100
OPM-I	26.1	3.9	77
OPM-PI	24.6	3.7	72
OPM-NI	24.6	3.7	72
CIC-BWE	21.1	3.1	62
OPM-NI-BWE	18.5	2.7	54

1/ Based on Delphi estimates (9).

The pounds of insecticides (a.i.) applied and IU indices reflect the expected conditions after full implementation of the programs. The IU indices would be higher during implementation. During the first year of the eradication programs, the IU index would likely be above 100 because of the larger number of fall diapause treatments. However, the absence of the boll weevil and the expected reduction in the use of insecticides would substantially improve the environmental quality in cotton production regions.

ECONOMIC IMPACTS (12)

Six boll weevil/cotton insect management programs were evaluated for their beltwide economic impacts: (1) Current Insect Control (CIC); (2) Optimum Pest Management with Continuing Incentive Payments for Boll Weevil Management (OPM-I); (3) Optimum Pest Management with Phased Incentive Payments for Boll Weevil Management (OPM-PI); (4) Optimum Pest Management with No Incentive Payments for Boll Weevil Management (OPM-NI); (5) Optimum Pest Management with No Incentives and with Boll Weevil Eradication (OPM-NI-BWE); and (6) Current Insect Control with Boll Weevil Eradication (CIC-BWE).

Key Assumptions and Procedures

The economic analysis was based on assumptions of average conditions, including weather, insect infestation, yields, and other exogenous variables. Also assumed in this analysis were current technologies, proven production practices, and current price relationships. To the extent that new technologies and shifts in relative prices impact differently on alternative programs, these assumptions may be invalid. However, forecasts of new technologies, their adoption rates, and changes in relative prices were avoided to simplify the analysis and avoid speculation.

The validity of the economic evaluation is highly dependent on the estimation of valid data on insecticide use, lint yields, and public expenditures for each of the proposed cotton insect management programs. The estimation of these critical beltwide data sets was a joint effort of the Biological and Economic Evaluation Teams (5,12).

Aggregate economic impacts of alternative programs on producers and consumers were estimated through the use of a national agricultural econometric-simulation model. Net market benefits associated with alternative cotton insect management programs were compared. This measure is an aggregate reflection of the net effects of changes in economic benefits and costs of alternative programs. It is a preferred criterion for ranking programs according to economic contributions to the nation as a whole. Benefit/cost ratios reflecting investment returns on public funds are useful in ranking programs when Federal and State budgets are severely constrained.

In the economic analysis, the term "consumers" has a very broad meaning and includes all market participants beyond the farm gate. Thus, in addition to including final consumers of processed agricultural crops, this definition includes processors of crops, such as gin owners and textile mills. Market participants between the farm gate and final consumers can also be viewed as consumers in the sense that they purchase goods for processing.

Impact of Technological Adoption

The aggregate impact of implementing technologies such as the proposed beltwide programs is that they raise levels of living and benefit society in general. However, the adoption of specific technology may or may not increase the income of the agricultural industry, in this case, the cotton industry. The manner in which the net income of cotton producers would be affected by the adoption of a beltwide cotton insect management program depends upon the price elasticity of demand for cotton and the effect of the program on (1) the total production of cotton, (2) the total costs for producing cotton, and (3) the nature of the shortrun supply function for production inputs such as seed, fertilizer, pesticides and capital.

The price elasticity of demand for most agricultural products, particularly the domestic demand for cotton, is inelastic. This means, in layman's terms, that percentage changes in quantities produced are less than percentage changes in prices. When demand is price inelastic, an increase in production of 5 percent will cause the price to decline by more than 5 percent. Conversely, if production is reduced by 5 percent, price will increase by more than 5 percent. If demand is inelastic, a fall in price causes consumers to spend less money on the commodity. A rise in price results in higher expenditures.

If demand is inelastic, how does one rationalize technological advancement when the industry would probably be better off economically without that technology? What actually happens over time, of course, is that the returns of some cotton operations are equal to or higher than their previous levels. However, it still holds true that total producers' incomes from commodities such as cotton would be greater in the absence of an increase in production.

The aggregate concept of technological adoption can be illustrated by a historical example of the public funding of water development. If the benefit cost ratios and the distributional impacts of water development in the Western States were examined, most likely it would be found that the opportunities to irrigate cotton in Arizona and California improved the competitive economic advantage of the Western cotton producers, cotton acreage shifted to the West and the Eastern cotton producers in the aggregate were worse off than they were before the development of the water projects in the West. The public benefited from these water projects, the Western Cotton producers received windfall profits, and the Eastern producers were disadvantaged.

It is always in the best interest of the individual producer to adopt cost reducing and/or output increasing technology. The earlier the technology is adopted the more it will increase the individual producer's net income. The extent to which cotton producers will adjust their production practices as a given program moves across the Belt is a function of the competitive position of cotton and other crops in each area. However, the gain from reduced cost of production and higher yields of cotton as a result of a beltwide program will decline as the program is adopted by more and more producers and implemented across the Cotton Belt.

The Economic Model (AGSIM)

An econometric-simulation model was designed specifically to estimate the aggregate economic impacts of policies or programs that change per acre crop yields and production costs. The model, referred to as AGSIM, includes acreage response functions for five major field crops (cotton, soybeans, corn, grain sorghum, and small grains) in the United States. Each acreage response function depends on expected per acre returns of that crop and competing crops, thereby allowing acreage shifts resulting from changes in per acre yields and production costs to be logically derived.

The total consumption side of the model involved consideration of many segments of the market. The basic cotton lint demand was modeled by two equations: one for mill demand and one for lint export demand. The price elasticity coefficient used for mill demand was -0.6 and is thus quite sensitive to changes in the available supply of cotton. The elasticity used for export demand was -1.0 and was less sensitive to changes in supply situations than domestic mill demand. The overall price elasticity of demand implied in this study was -0.8, which means that an 8 percent increase in production would be associated with a 10 percent drop in prices received. A small decrease in crop losses (increase in yields) due to insects can result in measurable decreases in prices received by farmers.

One advantage of the econometric model is that it is "positive" in the sense that it shows how producers and consumers have responded to changes in technology, relative profitability, and market forces in the recent past. The model is comprehensive enough to include export demand, regional acreage, and yield response. Another advantage of the model is that it implicitly accounts for many constraints such as gin capacity, managerial ability, and other resource constraints, which are very difficult if not impossible to include in normative activity analysis models. Finally, the model as constructed is based on an estimated adjustment time for yield and cost changes.

Beltwide Program Impacts

Compared with CIC, the alternative insect management programs had little effect on the acreage of cotton in the United States with changes of less than 0.1 percent in either direction (table 4). The analysis indicated a slight shift of acreage out of the Far West. The eradication programs would tend to halt the decline in acreage in Southeast and Mid-South areas where weevil infestations are historically high. However, many other factors also influence acreage levels.

Each of the program alternatives to CIC was found to favor and stabilize the U.S. cotton industry relative to foreign cotton producers and the synthetic fiber industry. Each program would lead to longrun increases, relative to CIC,

Table 4--Changes in cotton acreage, production, use and price for alternative boll weevil management programs 1/

Item	CIC base	Changes resulting from program:				
		OPM-I	OPM-NI	OPM-PI	CIC-BWE	OPM-NI-BWE
		1,000 acres				
Planted acreage 2/	12,690	+	-	-	+	+
	1,000 bales	Prcentage Change				
Production	11,657	2.0	1.7	1.7	2.1	2.8
Domestic fiber use	6,667	1.6	1.4	1.4	1.8	2.3
Lint exports	4,990	2.4	2.1	2.1	2.6	3.4
		Cents/pound				
Cotton prices	76.25	-2.0	-1.7	-1.7	-2.1	-2.7

1/ All values reflect full adjustment to each program.

2/ Acreage changed less than 0.1 percent in either direction.

in cotton production, mill use, and exports (table 4). No change in quality of product was assumed. Domestic mill use and exports would rise somewhat in response to price associated with increased production. Price declines range from 1.7 cents for OPM-PI and OPM-NI to 2.7 cents for OPM-NI-BWE.

National average prices of major competing field crops other than sorghum would decline slightly, less than 0.3 percent. This would occur as a result of substitution effects associated with each cotton insect management alternative as more cottonseed oil and meals were substituted for other feed grains and oils, and as acreage shifted among crops.

Compared with CIC, all programs reduce average cotton production costs, raise average yields, and in the long run, increase cotton production and net incomes in areas that, historically, are heavily infested with boll weevils (table 5). Net incomes of producers in lightly-infested areas and in weevil-free areas would decline as a result of lower national prices caused by increased production in infested areas. The increase in cotton production nationally and the resulting lower prices to mills, exporters, and consumers would benefit these market participants and would substantially offset the lower net returns to some producers and the public costs of the programs.

Annual changes in net market benefits varied considerably by program and by year during implementation (fig. 6). Benefits of the three OPM programs increased steadily during implementation and were stabilized for these programs by the fifth year. Net benefits were negative for CIC-BWE and low for OPM-NI-BWE in early years because of high program costs and increasing program benefits. Net benefits stabilized for the two eradication programs by the twelfth year.

It was estimated that the OPM-NI-BWE program would produce the highest net benefits, based on discounted future benefits and costs. 3/ They were $3.9 billion higher than with current insect control methods (table 6). Consumers would gain chiefly because the increased production would lower prices of lint and cottonseed products. Also, adjustments among competing crops such as soybeans, corn, and small grains would result in slightly lower

---

3/ Discounting is a mathematical process of reducing costs or benefits that occur in future years to a common point in time so that they can be added and compared (14). Discounting techniques are used in most types of analysis where costs and benefits occur over a period of time. Discounting is a traditional technique used by both private industry and Government in evaluating alternative investment proposals. Procedures used in discounting are specified in OMB Circular No. A-94, revised, which apply to the evaluation of Government decisions which "commit the Government to a series of measurable costs extending over 3 or more years or which result in a series of benefits that extend 3 or more years beyond the inception date."

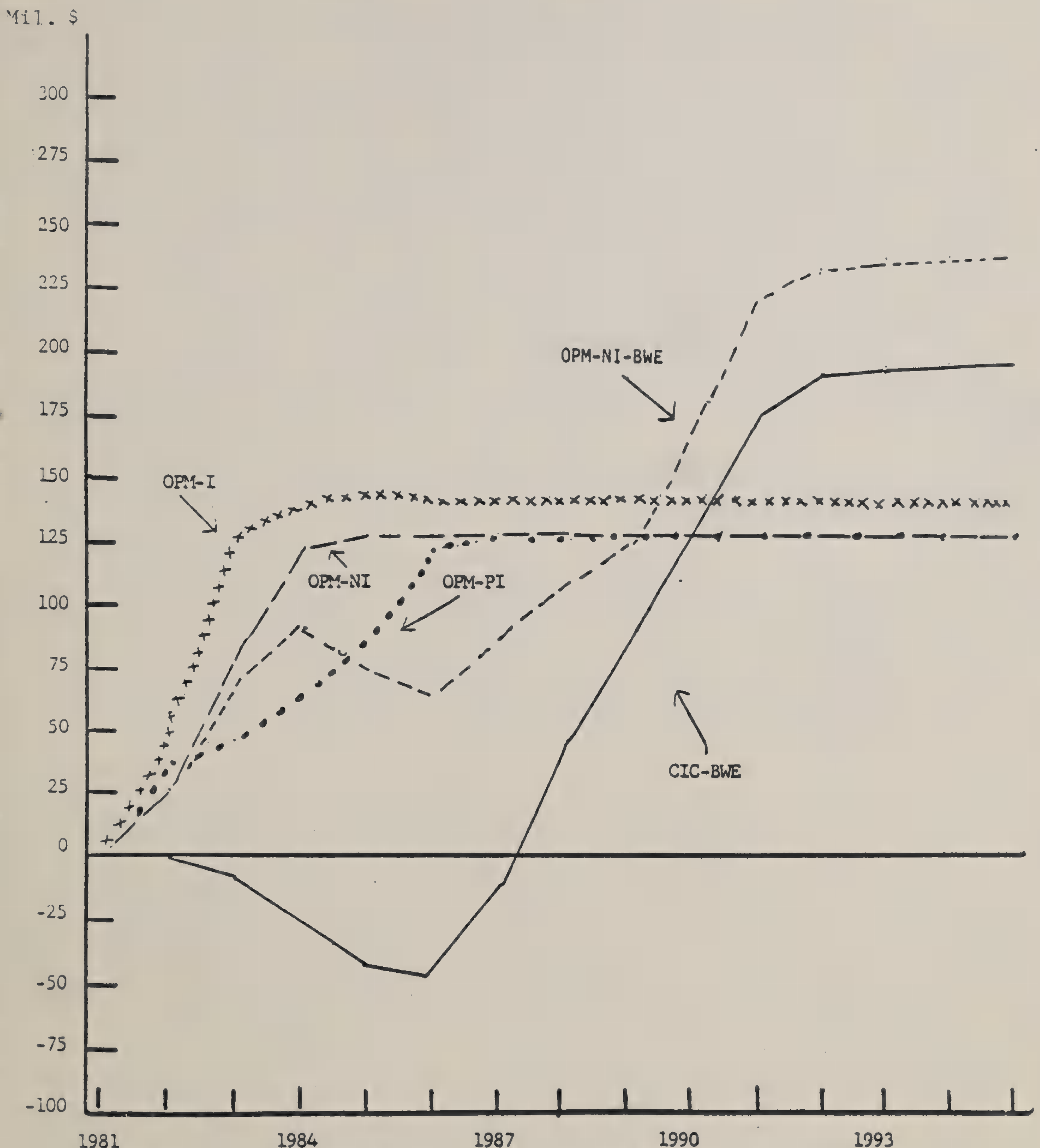
Table 5--Longrun changes in annual total net returns and returns per acre to cotton producers by boll weevil infested and weevil free areas

Areas 1/	Changes in net returns due to: 2/				
	OPM-I	OPM-NI	OPM-PI	CIC-BWE	OPM-NI-BWE
	Million dollars				
Total net returns					
Weevil infested	54	28	28	67	69
Weevil free	-84	-71	-71	-88	-117
Returns/acre	Dollars				
Weevil infested	8.01	4.15	4.15	13.71	14.12
Weevil free	-17.19	-14.53	-14.53	-18.00	-23.94

1/ Location of weevil infested and weevil free areas is shown in figure 7.

2/ All values reflect full implementation of each program.

Figure 6. CHANGE IN ANNUAL NET MARKET BENEFITS



Net benefits evaluated as a change from CIC. All programs are initiated in 1982

Table 6--Net present value of market benefits and B/C ratios for alternative boll weevil/cotton insect management programs 1/

Item	Changes from CIC programs				
	OPM-I	OPM-PI	OPM-NI	CIC-BWE 2/	OPM-NI-BWE 2/
Net market benefits ($ billion) 3/	3.1	2.5	2.6	2.8	3.9
B/C ratio 4/	8:1	21:1	44:1	18:1	17:1

1/ Net present value of market benefits and B/C ratios represent changes in present values compared with benefits and costs of the Current Insect Control (CIC) program. Future benefits and costs in 1979 dollars were discounted at 7-1/8 percent in perpetuity.

2/ Producers were assumed to pay 50 percent of eradication program costs, exclusive of capital costs and followup monitoring. Producer shares of program costs are reflected in returns to cotton production.

3/ Net benefits equal the sum of consumer and producer benefits less program costs paid by the government. They are generally considered the best criterion for decision if there are no budget constraints.

4/ B/C ratios were calculated as the sum of consumer and producer benefits divided by public program costs. They are generally considered the best criterion for decision if there are budget constraints.

prices (less than 0.3 percent) for those crops. Federal and State Government expenditures under this alternative would total about $350 million during the 12 years required to fully implement the program across the Cotton Belt, assuming that producers would share 50 percent of eradication costs.

The highest benefit-cost ratio was obtained for the OPM-NI program (table 6). As shown in this analysis, a program having the highest benefit-cost ratio is often not the option that maximizes net benefits to society.

The discounted long-term net benefits of other programs ranged from a gain of $3.1 billion for the OPM-I program to a gain of $2.5 billion for the OPM-PI program (table 6). As with most productivity-increasing technologies, the early adopters are able to capitalize on the gains. Those producers unable to avail themselves of the technology are at a comparative disadvantage. Consumers, including all market participants beyond the farm gate, however, are the ultimate beneficiaries.

Public expenditures in the long run were highest for the OPM-I program followed by OPM-NI-BWE, CIC-BWE, OPM-PI and OPM-NI.

Sensitivity Analysis

To establish some possible bounds for the aggregate economic estimates, sensitivity analyses provided an indication of how a wide range of possible yields, discount rates, cost-sharing arrangements and implementation schedules would affect the distribution of net benefits. OPM-NI-BWE retained its top ranking in terms of maximum net benefits in all cases, and OPM-NI retained its top ranking in terms of the highest rate of return on Federal funding.

Secondary Impacts

Interindustry impacts of alternative programs were further explored through the use of an input-output model. The results showed the distributional effects among the major sectors of the cotton industry and other sectors of the U.S. economy. In terms of total economic activity generated, the ranking of insect management programs was identical with the ranking of net benefits obtained from the AGSIM model. In the cotton ginning, warehousing, and merchandising sectors, the OPM-NI-BWE program ranked highest in generation of economic activity, followed by CIC-BWE and OPM-I.

DECISION ANALYSIS OF PROGRAM IMPACTS

A conceptual framework for program evaluations is briefly reviewed to assist in interpreting the results of the evaluations and to keep the differences among the programs in proper perspective. The technical and operational feasibility is examined as a necessary criterion for implementing a program. Lastly, the specific impacts of each of the six beltwide programs are ranked as a basis for identifying the programs with the most desirable biological, economic, and environmental characteristics and those most viable for beltwide implementation.

Institutional, regulatory, and social factors are not discussed even though they may weigh heavily in the choice of a beltwide program. Consideration of these factors was not a requirement of the overall evaluation.

Conceptual Framework

The conceptual framework for all program evaluations is similar. The evaluation of a single program or several programs, whether they relate to insect control, commodities, or social issues, begins with the known and quickly moves into the area of unknowns or uncertainties. Most of the information available for a decision on which program to implement falls within the area of uncertainty. The understanding of this concept is important as one examines the quantitative as well as qualitative differences among programs.

The trials, past and current research on cotton insect management, and experience of extension and private pest management specialists provide the known information base. The transition from the known information base to the estimation of beltwide impacts of alternative programs must rely on specific biological, economic, and ecological principles. These principles guide the various diciplines in developing their analytical plans and models and in interpreting the results. Nevertheless, all the estimates of beltwide program impacts (except CIC) fall within the area of unknowns and uncertainties.

The level of confidence in an evaluation is mainly a function of the complexities of the programs analyzed, the extent of the known data base and how well it was utilized, and the analytical tools and interpretive skills of the analysts. The advantages and disadvantages of alternative programs should be based primarily on the information assembled and interpreted by the analysts. However, the choice of a program will most certainly involve political and budget considerations and the intuitive judgment of administrators and decisionmakers.

Technical and Operational Feasibility

A comparative decision analysis begins with the assumption that the programs, as defined, are technically and operationally feasible. We should have a high probability that the five proposed cotton insect management programs

can be organized, that personnel and equipment will be available as needed, and that the biological components will yield results as predicted, i.e., reduced need for insecticide use and increased lint yields. This is a necessary criterion, but it is not sufficient for a decision.

The two boll weevil/cotton insect management trials, conducted during 1978-80, demonstrated the technical and operational feasibility either to eradicate an established boll weevil population from a specified geographic area or to eliminate the need for mid-season boll weevil treatments. When beltwide feasibility is considered, we make the first transition from known information to the area of uncertainty. On the basis of the trials, previous research, and experience in managing cotton insects, we assume that the proposed beltwide programs, as defined and specified in the terms of program costs, insecticide use and lint yields, are technically and operationally feasible for implementation. A review of the definitions and specifications of the beltwide program will indicate that they are not replicates of the trials but rather modifications that recognize the differences in cotton production practices, insect populations, weather, and other variables that affect insect control management practices.

Ranking of Projected Impacts of Programs

As indicated earlier, all estimates of projected impacts of the beltwide programs are in the area of uncertainty rather than known. Thus, an examination of the relationships among programs is more relevant and valid than an evaluation based on point estimates. Absolute differences among programs may not be valid. Small absolute differences between programs generally cannot be considered a basis for preferring one program over another. For comparison, all point estimates of biologic, economic, and environmental impacts of the alternative programs were converted to ordinal rankings (table 7).

Current Insect Control (CIC) Program. CIC remains a viable program for continuation. It is in place and has a history of accomplishments. It would require the least Federal funds. Also, there would be no change in the distributional effects of the program beltwide. Although the original allocation of funds to support CIC was based on the extent of insect control problems in each State, an examination of the funding may provide an opportunity to increase benefits by reallocating some of the funds to areas where insect problems remain the most serious. Disadvantages of CIC include most complete reliance upon broad spectrum insecticides, continued potential development of resistance by pests, and limitations on the use of naturally occurring beneficial insects. Additionally, CIC would have higher costs for insecticides and lower yields than the proposed programs.

OPM-I and OPM-NI-BWE Programs. The major components of these two programs were validated during the 3-year trials. Other than CIC, most is known about these programs. The OPM-I program is not as complex as OPM-NI-BWE and thus it should have the highest probability of success other than the current pro-

Table 7--Ranking of impacts of beltwide boll weevil/cotton insect management programs 1/

Item	CIC	OPM-I	OPM-PI	OPM-NI	CIC-BWE	OPM-NI/BWE
Biological						
Smallest quantity of insecticides, a.i.	5	4	3	3	2	1
Highest lint yields/acre	4	2	3	3	2	1
Lowest risk of insecticide resistance	5	4	3	3	2	1
Economic						
Lowest total producer insecticide costs	5	3	4	4	2	1
Lowest public funds	1	6	3	2	4	5
Largest increase in producer incomes, weevil areas 2/	NA	3	4	4	2	1
Smallest decrease in producer incomes, weevil free areas 2/	NA	2	1	1	3	4
Reduction in consumer prices of cotton fiber and other commodities 2/	NA	2	3	3	4	1
Total market benefits 2/	NA	2	5	4	3	1
B/C ratio 2/	NA	4	2	1	3	3
Increase in exports/improved balance-of-payments 2/	NA	2	3	3	2	1
Environmental						
Improved environmental quality	5	4	3	3	2	1

1/ Ranking based on 1 = best, 6 = worst.

2/ The ranking of these variables represent marginal changes from CIC.

NA = Not applicable.

gram. The only other favorable characteristic of OPM-I is that it would minimize the distributional impact on cotton producers more than OPM-NI-BWE. More explicitly, because of only a small reduction in insecticide use and a moderate increase in lint yields, net incomes to producers in the weevil area would not be increased very much while at the same time the income of producers in the weevil area would not be reduced as much as with OPM-NI-BWE (table 7). All other variables are more positive for OPM-NI-BWE and of the two programs it is the more viable alternative.

OPM-PI and OPM-NI Programs. These two programs are ranked identically on most variables (table 7). However, the OPM-NI program requires less public funds and the net market benefits and benefit cost ratio are higher. Neither OPM-NI nor OPM-PI were field tested in large scale trials. Thus, their probability of success is similar. Only a small percentage of acreage under these two programs would be expected to have effective diapause control. Overall, OPM-NI appears to be the most viable of the two programs because of equal or higher ranking on all variables.

CIC-BWE and OPM-NI-BWE. In many respects, the two boll weevil eradication programs are the most complex to analyze because the eradication component of these programs requires 9 years for full implementation. The stream of private and public costs as well as the benefits change year-by-year as the programs are implemented. An examination of the rankings of the two eradication programs shows that OPM-NI-BWE is higher than CIC-BWE for all variables except public funds required for implementation, and the reduction in income of producers in weevil-free areas (table 7). The probability of success should be higher for the OPM-NI-BWE program than the CIC-BWE program mainly because the technology used in the BWE trial was more similar to the OPM-NI-BWE program. In view of these rankings, CIC-BWE can be rejected as a viable program for beltwide implementation.

In summary, the CIC, OPM-NI and OPM-NI-BWE programs remain the most viable for beltwide implementation. The OPM-I, OPM-PI and CIC-BWE programs were less desirable based on their lower ranking on most of the variables.

The CIC program ranks first in terms of least cost. Additionally, there may be opportunities for improvement based on reallocation of the current public funding to those areas with the greatest insect problems. OPM-NI is the second lowest cost program with moderate benefits to society and the highest B/C ratio of the five proposed programs. The OPM-NI-BWE program ranks first in regard to lower prices to consumers, improved environmental quality, reductions in use of insecticides, reductions in cost of production, increases in cotton yield and increases in net income of producers in the weevil-infested areas. It has a reasonably high probability of success. Its main disadvantage is that, with the higher public costs, its B/C ratio is lower than that of OPM-NI.

OTHER CONSIDERATIONS

Insecticide Resistance (10)

The risk of insecticide resistance is a continuing long term complex problem. However, because of the serious economic consequence of potential insecticide resistance of the key cotton pests, it should be recognized in considering the merits of the proposed beltwide cotton insect management programs. Because of the various kinds of insecticides and intensity of use, the risk of development of insecticide resistance strains of the boll weevil or *Heliothis* are different.

The eradication of the boll weevil improves the prospects of either using fewer insecticides or employing noninsecticidal methods for *Heliothis* management. The results would be that natural biological control agents would have a greater effect in regulating *Heliothis* populations and the alternative methods available and broad spectrum insecticides would not have to be employed as frequently. Therefore, the possibilities of the development of resistant strains to whatever management procedures might be used are less likely in the absence of the weevil.

Although it is difficult to predict or estimate the probability of a pest species becoming resistant to specific chemicals, one of the important variables is the extent of insecticide use. Thus, a comparison of the proposed beltwide programs based on the quantities of insecticide use provides a proxy for the risk of insecticide resistance. The boll weevil eradication program, after implementation, would require the smallest quantity of insecticides and should be the least likely to cause insecticide resistance to *Heliothis*. Based on acre insecticide treatments, risk indices for insecticide resistance for the beltwide programs follow:

Program	Treatments by insecticides		Resistance risk index
	---------Million acres-------------		
CIC	35	=	100 (greatest risk)
OPM-I	34		97
OPM-PI	31		89
OPM-NI	31		89
CIC-BWE	25		71
OPM-NI-BWE	24		69

An index based on the mix of insecticides and intensity of use would be a more accurate assessment of the risk. However, the relative ranking of the programs would not likely change. These indices indicate that CIC and the regular OPM programs would have highest risk of resistance to insecticides for both the boll weevil and *Heliothis*. The eradication programs would have relatively low risk of resistance to the *Heliothis*.

Restrictions on Pest Control Technology

Recent developments in technology available for cotton insect control have been restricted by actions of regulatory agencies. These actions have restricted development of chemical insecticides to those of short residual activity, nonpersistence in soil and plants, and greater biological selectivity, all of which have increased cost of insecticides. However, such regulatory restrictions are serving a useful purpose in that they encourage development of a more precise insect management system. Although the overall impacts of regulatory actions may result in short-term increased costs to the producer, improved methods of managing cotton insects should provide greater long-term benefits.

Although all proposed programs would require fewer insecticides than current practices, the two eradication programs would likely be impacted the least by future restrictions on the use of insecticides.

Energy Efficiency

Efficient production of cotton in the U.S. has become highly dependent on the use of fossil fuels. The substantial increases in cotton productivity over the past three decades have been based chiefly on the substitution of mechanical power and equipment for animal power and labor and the use of energy intensive pesticides and fertilizer as a substitute for land. Cotton farmers have adjusted to the rapidly increasing cost of energy since 1974. However, they face future increases in energy prices and thus any gains in energy efficiency in the use of insecticides and land will help the cotton industry to remain economically viable through an improved competitive position in the world cotton market and with synthetic fibers as well (15).

In the aggregate, energy costs to U.S. cotton producers totaled an estimated $275 million in 1976. This translates into about $24 per acre, or 15 percent of variable costs and 8 percent of total costs of production. These characterizations of energy mix, use, and cost differ widely among regions (15).

Agricultural production accounts for less than 3 percent of all energy used in the United States. The 100 trillion British thermal units (Btu)--equivalent to more than 17 million barrels of oil--of energy used in producing U.S. cotton represents about 5 percent of agricultural use (16). About 40 percent of cotton energy use is indirect, in the form of energy (primarily natural gas)

required to manufacture fertilizers and pesticides. Well over half of the direct energy is represented by refined petroleum products used in field operations and in farm business transportation.

All the proposed cotton insect management programs would reduce energy use indirectly through less use of insecticides and directly by requiring fewer applications of insecticides and producing more lint per acre. The conversion of these changes into an index of efficiency in energy use provides an indication of the relative levels of energy efficiency of each program as follows:

Program	Pounds of insecticides 1/ (a.i.)	Pounds of cotton lint 1/	Index of energy efficiency 2/
	Million pounds		
CIC (baseline)	34.0	2,890	100 (highest energy use)
OPM-I	26.1	3007	136
OPM-PI	24.6	2991	143
OPM-NI	24.6	2991	143
CIC-BWE	21.1	3006	168
OPM-NI-BWE	18.5	3045	194

1/ Based on Delphi estimates.

2/ Based on calculation of pounds of lint produced per pound of active insecticide ingredient applied.

All proposed programs would save energy compared with CIC. The two eradication programs would be expected to have the greatest reduction on energy use per pound of cotton produced.

REFERENCES

1. Townsend, C.H.T., "Report on the Cotton Boll Weevil in Texas (Anthonomus grandis Boh.)" Insect Life, Vol. 7, No. 4, 1895, pp. 295-309.

2. Overall Plan for a National Program to Eliminate the Boll Weevil from the United States. Report of a Technical Subcommittee appointed by the National Cotton Council of America. December 4, 1973.

3. Agriculture and Consumer Protection Act of 1973. Public Law 93-86, 93rd Congress, S.1888, August 10, 1973.

4. "Operation and Evaluation Plans, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix H. APHIS Staff Report, January 1980.

5. "Biological Evaluation, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix A. SEA-AR Staff Report April 1981.

6. "Optimum Pest Management Trial, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix G. Cooperative Extension Service, Mississippi State University Report, April 1981.

7. "Boll Weevil Eradication Trial, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix F. APHIS Staff Report, April 1981.

8. "Program Definitions and Public Costs, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix D. ESS Staff Report No. AGESS810504, May 1981.

9. "The Delphi: Insecticide Use and Lint Yields, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix E. ESS Staff Report No. AGESS810507, May 1981

10. Knipling, E.F., "Boll Weevil Eradication Versus Year to Year Management--In Perspective." Unpublished statement, February 1981.

11. "Environmental Evaluation of Alternative Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix C. APHIS 81-33, April 1981.

12. "Economic Evaluation, Beltwide Boll Weevil/Cotton Insect Management Programs." Overall Evaluation Appendix B. ESS Staff Report AGESS810518, May 1981.

13. Mann, Jitendar S., "Techniques to Measure Social Benefits and Costs in Agriculture: A Survey." Agricultural Economics Research, Vol. 29, No. 4, October 1977, pp. 115-126.

14. Baumol, W.J., "On the Social Rate of Discount." Amer. Econ. Review, Vol. 58 (1968) 788-802.

15. VanArsdall, R. Thomas and I. Starbird, "Energy, Another Dilemma Faced by Cotton," U.S. Department of Agriculture, Economics and Statistics Service, January 1978.

16. U.S. Department of Agriculture, Economics and Statistics Service, Energy and U.S. Agriculture: 1974 Data Base, Volume 2. "Commodity Series," Federal Energy Administration, August 1977.

*U.S. GOVERNMENT PRINTING OFFICE : 1981 O-340-932/ESS/ERS-187